CHAPTER 4

AVAILABILITY

INTRODUCTION

Availability is the parameter that translates system reliability and maintainability characteristics into an index of effectiveness. It is based on the question, "Is the equipment available in a working condition when it is needed?" The ability to answer this question for a specific system represents a powerful concept in itself, and there are additional side benefits that result. An important benefit is the ability to use the availability analysis as a platform to support both the establishment of reliability and maintainability parameters and trade-offs between these parameters. As part of our review of availability, we will separate maintainability into its components (preventive and corrective maintenance and administrative and logistics delay times) to determine the impact of these individual elements on overall system availability.

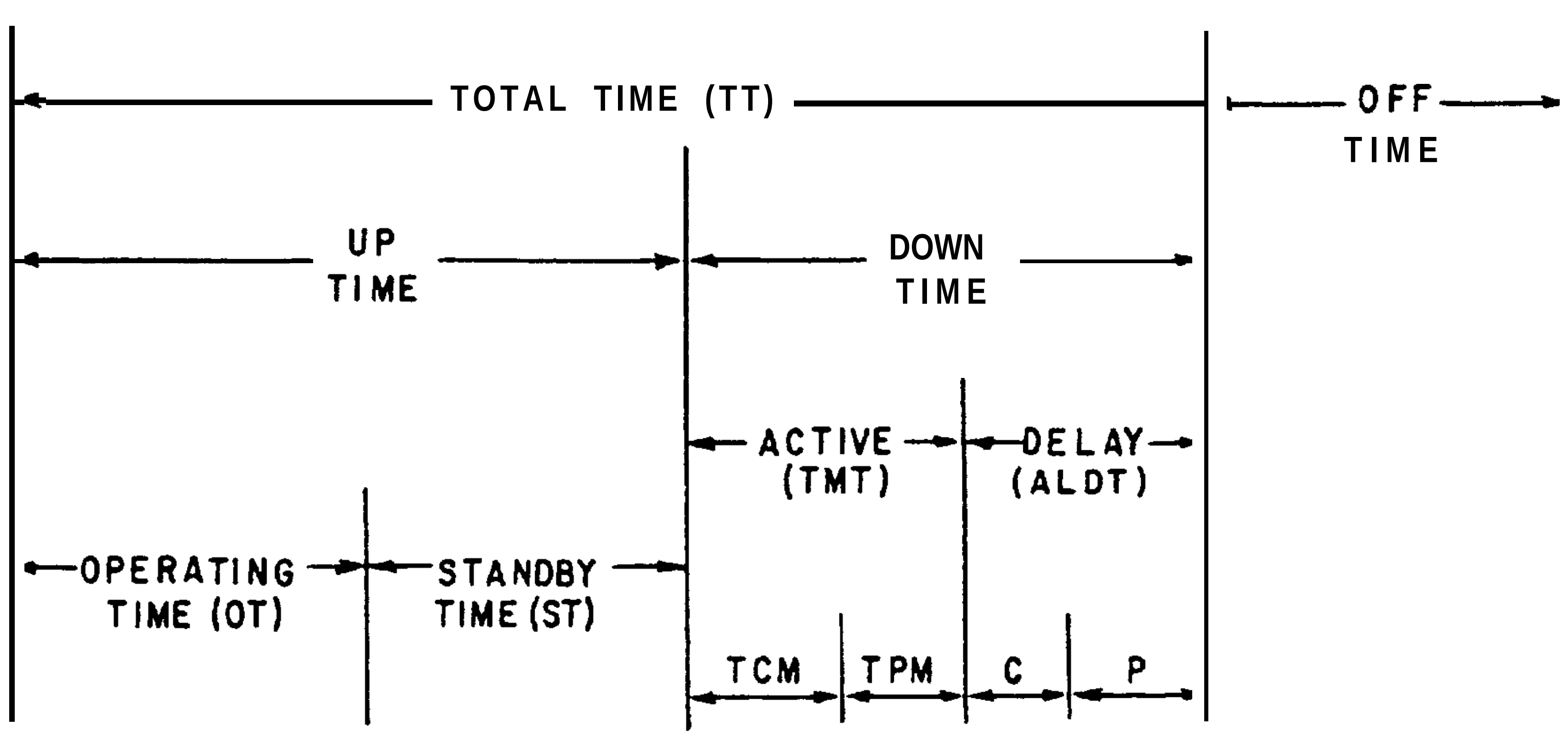
DEFINITION OF AVAILABILITY

Availability is defined as a measure of the degree to which an item is in an operable and committable state at the start of a mission when the mission is called for at a random point in time.

ELEMENTS OF AVAILABILITY

As is evident by its very nature, approaches to availability are time-related. Figure 4-1 illustrates the breakdown of total equipment time into those time-based elements on which the analysis of availability is based. Note that the time designated as "off time" does not apply to availability analyses because during this time system operation is not required. Storage and transportation periods are examples of "off time".

FIGURE 4-I. BREAKDOWN OF TOTAL EQUIPMENT TIME



The letters "C" and "P" represent those periods of time attributed to corrective or preventive maintenance, respectively, which are expended in active repair of hardware or in waiting (delay) for resources to effect needed repairs. This waiting or delay period can further be subdivided into administrative and logistics delay periods.

DEFINITION OF TERMS

Definitions of commonly used availability elements are given below. Several are displayed pictorially in Figure 4-1.

TT	=	Total intended utilization period, total time.
TCM	=	Total corrective (unscheduled) maintenance time per specified period.
TPM	=	Total preventive (scheduled) maintenance time per specified period.
ALDT	=	Administrative and logistics down time spent waiting for parts, administrative processing, maintenance personnel, or transportation per specified period. See Figure 4-1, Delay-Down Time (no maintenance time).
TMT	=	Total maintenance time = TCM + TPM. See Figure 4-1, Active-Down Time.
TDT	=	Total down time = TMT + ALDT.
OT	=	Operating time (equipment in use). See Figure 4-1.
ST	=	Standby time (not operating but assumed operable) in a specified period. See Figure 4-1.
MTBF	=	Mean time between failures.
MTBM	=	Mean time between maintenance actions.
MTBUMA	=	Mean time between unscheduled maintenance actions (unscheduled means corrective).
MDT	=	Mean down time.
MTTR	=	Mean time to repair.

MATHEMATICAL EXPRESSIONS OF AVAILABILITY

The basic mathematical definition of availability is

$$\text{Availability} = A = \frac{\text{Up Time}}{\text{Total Time}} = \frac{\text{Up Time}}{\text{Up Time + Down Time}} \tag{4.1}$$

Actual assessment of availability is accomplished by substituting the time-based elements defined above into various forms of this basic' equation. Different combinations of elements combine to formulate different definitions of availability.

Operational availability is the most desirable form of availability to be used in assessing a system's combat potential. Achieved, and to a lesser degree inherent availability are primarily the concern of the developing agency in its interface with the contractor and other co-developing agencies.

Ao is an important measure of system effectiveness because it relates system hardware, support and environment characteristics into one meaningful parameter-- a figure of merit depicting the equipment state at the start of a mission. Because it is an effectiveness-related index, availability is used as a starting point for nearly all effectiveness and force sizing analyses.

Inherent Availability (Ai)

Under certain conditions, it is necessary to define system availability with respect only to operating time and corrective maintenance. Availability defined in this manner is called inherent availability (Ai).

$$A_i = \frac{MTBF}{MTBF + MTTR} \tag{4.2}$$

Under these idealized conditions, we choose to ignore standby and delay times associated with scheduled or preventive maintenance, as well as administrative and logistics down time. Because only corrective maintenance is considered in the calculation, the MTBF becomes MTBUMA, and, likewise, MTTR is calculated using only times associated with corrective maintenance.

Inherent availability is useful in determining basic system operational characteristics under conditions which might include testing in a contractor's facility or other controlled test environment. Likewise, inherent availability becomes a useful term to describe combined reliability and maintainability characteristics or to define one in terms of the other during early conceptual phases of a program when, generally, these terms cannot be defined individually. Since this definition of availability is easily measured, it is frequently used as a contract-specified requirement.

As is obvious from this definition, inherent availability provides a very poor estimate of true combat potential for most systems, because it provides no indication of the time required to obtain required field support. This term should normally not be used to support an operational assessment.

Case Study No. 4-1 displays the usefulness of inherent availability.

Operational Availability (Ao)

Operational availability, unlike inherent availability, covers all segments of time that the equipment is intended to be operational (total time in Figure 4-l). The same up-down time relationship exists but has been expanded. Up time now includes operating time plus nonoperating (stand-by) time (when the equipment is assumed to be operable). Down time has been expanded to include preventive and corrective maintenance and associated administrative and logistics lead time. All are measured in clock time.

$$\text{Operational Availability} = A_o = \frac{OT + ST}{OT + ST + TPM + TCM + ALDT} . \qquad (4.3)$$

This relationship is intended to provide a realistic measure of equipment availability when the equipment is deployed and functioning in a combat environment. Operational availability is used to support operational testing assessment, life cycle costing, and force development exercises.

One significant problem associated with determining Ao is that it becomes costly and time-consuming to define the various parameters. Defining ALDT and TPM under combat conditions is not feasible in most instances. Nevertheless, the operational availability expression does provide an accepted technique of relating standard reliability and maintainability elements into an effectiveness-oriented parameter. As such, it is a useful assessment tool.

Case Study 4-4 illustrates how this relationship can be used to define and analyze the various elements of reliability and maintainability. Case Study 4-2 illustrates the calculation of Ao.

One important aspect to take note of when assessing Ao is that it is affected by utilization rate. The less a system is operated in a given period, the higher Ao will be. It is important therefore when defining the "total time" period to exclude lengthy periods during which little or no system usage is anticipated. Case Study 4-3 attempts to display this characteristic of Ao.

One other frequently encountered expression for operational availability is

$$A_o = \frac{MTBM}{MTBM + MDT} . \qquad (4.4)$$

where

MTBM = mean time between maintenance actions and MDT = mean down time.

While maintenance-oriented, this form of Ao retains consideration of the same basic elements. The MDT interval includes corrective and preventive maintenance and administrative and logistics down time. This form of the Ao relationship would generally prove more useful in support of early maintenance parameter sensitivity and definition analysis. Note that the above definition assumes that standby time is zero.

Achieved Availability (As)

This definition of availability is mathematically expressed as

$$A_a = \frac{OT}{OT + TCM + TPM} \qquad (4.5)$$

Aa is frequently used during development testing and initial production testing when the system is not operating in its intended support environment Excluded are operator before-and-after maintenance checks and standby, supply, and administrative waiting periods. Aa is much more a system hardware-oriented measure than is operational availability, which considers operating environment factors. It is, however, dependent on the preventive maintenance policy, which is greatly influenced by non-hardware considerations.

A GENERAL APPROACH FOR EVALUATING AVAILABILITY

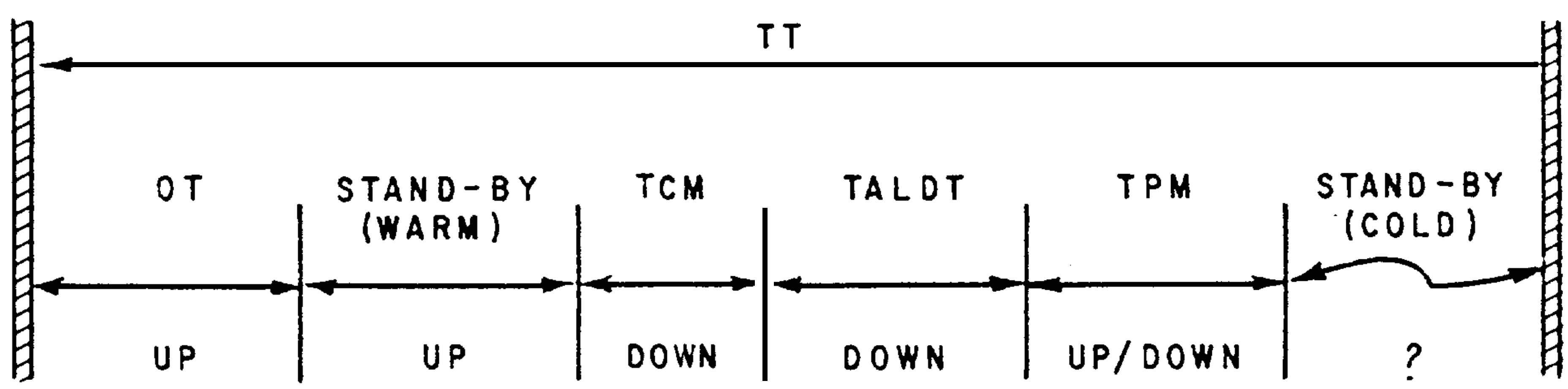
The following paragraphs present a generalized approach for evaluating system availability. It is important to note that for such an analysis to be meaningful to an equipment user or developer it must reflect the peculiarities of the system being considered.

General Procedure

1. The operational and maintenance concepts associated with system utilization must be defined in detail using terminology compatible with the user, developer and contractor.

2. Using the above definitions, construct a time line availability model (see Figure 4-2) which reflects the mission availability parameters.

FIGURE 4-2 MISSION AVAILABILITY TIME LINE MODEL GENERALIZED FORMAT



NOTE : Figure 4-2 displays elements of availability frequently included in a quantitative assessment of availability. The up or down status of a specific system during preventive maintenance must be closely examined. Generally, a portion of the preventive maintenance period may be considered as uptime. Cold standby time must also be examined closely before determining system up or down status during this period.

3. With the aid of the time line model, determine which time elements represent "uptime" and "downtime." Don't be mislead by the apparent simplicity of this task. For example, consider that the maintenance concept may be defined so that the equipment must be maintained in a committable state during the performance of preventive maintenance.

Additionally, for multi-mission and/or multi-mode systems, it will be necessary to determine up and down times as a function of each mission/mode. This generally will require the use of a separate time line model for each identifiable mission/mode.

Likewise, separate time line models are generally required to support the availability analyses of systems which experience significantly different peacetime, sustained combat and surge utilization rates.

4. Determine quantitative values for the individual time elements of the 'time line models. Coordinate these values with the user, developer and contractor.

5. Compute and track availability using the definitions of availability appropriate for the current stage of system development.

6. Continue to check availability model status and update the model as required. Special attention should be given to updating the model as the operational , maintenance, and logistics support concepts mature.

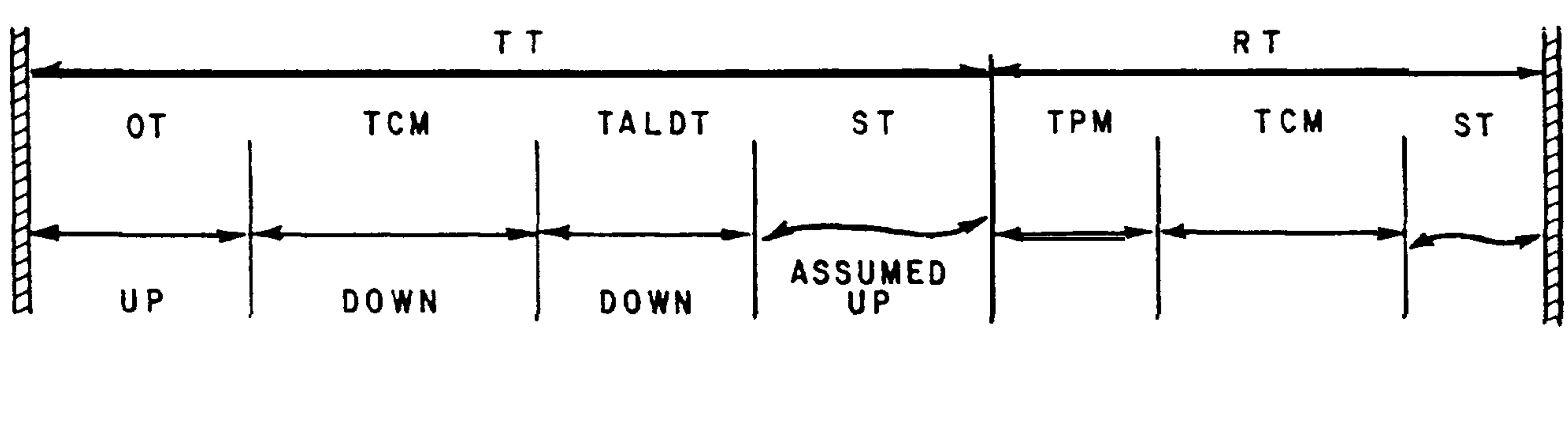
System Availability Assessment Considerations

As indicated in the above paragraphs, the quantitative evaluation of availability must be carefully and accurately tailored to each system. For this reason, no detailed examples are presented in this text. However, the following paragraphs do present concepts which will apply to various classes of systems.

Recovery Time. Normally, availability measures imply that every hour has equal value from the standpoint of operations and the performance of maintenance and logistics activities. Normally, the operational concept requires the system to function only for selected periods. The remaining time is traditionally referred to as "off-time," during which no activity is conducted.

An alternative to the "off-time" or "cold. standby" concepts is the use of the term "recovery time" (RT).

FIGURE 4-3 MISSION AVAILABILITY TIME LINE MODEL RECOVERY TIME FORMAT



Recovery time represents an interval of time during which the system may be up or down. Recovery time does not appear in the availability calculation which is based only on the TT time period. Take special note of the fact that corrective maintenance time (TCM) is found in both TT and RT time intervals. Corrective maintenance performed during the TT period is maintenance required to keep the system in a mission ready or available status. Corrective maintenance performed during the RT period generally addresses hardware malfunctions which do not result in a non mission-ready status.

The principal advantage of using the "recovery time" analysis is that it can provide a more meaningful availability assessment for systems whose periods of required availability are predictable and whose preventive maintenance constitutes a significant but delayable portion of the maintenance burden.

The recovery time calculation technique concentrates the availability calculation during the operational time period, thereby focusing attention on critical up and down time elements.

The above discussion presents an alternate technique of computing system availability, i.e., the use of the recovery time concept. Whatever technique is selected for computing availability, it must be carefully tailored to *the* system undergoing assessment

Definition of the terms used in availability analysis must be stressed. For example, what total time (TT) period has been chosen for an analysis base? Assume for a moment that we are assessing the A_o of an operational squadron and that we have chosen a 7-day TT period. If the aircraft normally are not flown on weekends or are left in an up condition on Friday night it is obvious that Ao will be higher than if a 5-day total time were selected. Reference the discussion of recovery and standby time. See Case Study 4-3.

Other definitions associated with Ao are not quite so obvious and must be included in pretest definition. For example, are "before and after" operational checks conducted in conjunction with preventive maintenance excluded from down time because the equipment is assumed operable? Similarly, are corrective maintenance diagnostic procedures logged against down time? What if the hardware is not found defective? How is ALDT arrived at? Is it assumed, calculated or observed? What is the operational status of a system during the warm standby period?

HARDWARE REQUIREMENT ESTABLISHMENT AND TRADE-OFFS

The expression for availability frequently provides the vehicle needed to analyze other system requirements both directly and by way of trade-offs. Case Studies 4-4 and 4-5 provide examples of this application.

AVAILABILITY FOR MULTI-MISSION SYSTEMS

For many modern weapon systems, availability is not simply an "up" or "down" condition. Systems such as AEGIS and HAWK have multi-mission/mode capabilities and thus require detailed techniques to characterize the associated availability states. While these multi-mission/mode characterizations may appear different, they are indeed based on the expressions presented previously. The definition of terms, modes and states is equally important in the analysis of these complex systems. The reliability of a multi-mission system is examined in Case Study 2-7.

SIMULATION MODELS

There are a number of computer simulation models available which are well suited for evaluating interactions between system design characteristics, logistic support, and relevant operational output measures such as operational availability or sortie rate. Examples of such models include LCOM (aircraft), CASEE and PRISM (carrier-based aircraft), ARMS (Army aircraft), TIGER (Ship systems), RETCOM (combat vehicles), etc. These models provide visibility of manpower and test equipment, queueing effects, and the impact of spares stockage levels on operational availability, which generally cannot be evaluated with simple analytical formulas. Simulation models are particularly useful for using test results to project operational availability under conditions different from the test environment (e.g., to project availability under wartime surge conditions). One drawback to simulation models is that they are usually more cumbersome to use than straightforward analytical techniques.

CASE STUDY NO. 4-1

Background

Early in the development phase of a new avionics system, it is determined that an inherent availability of 0.92 is required. The reliability and maintenance engineering personnel in the program office desire to analyze only what effect this requirement has on the relationship between their disciplines, which is appropriate in a first-look consideration.

Determine

How can this analysis be accomplished?

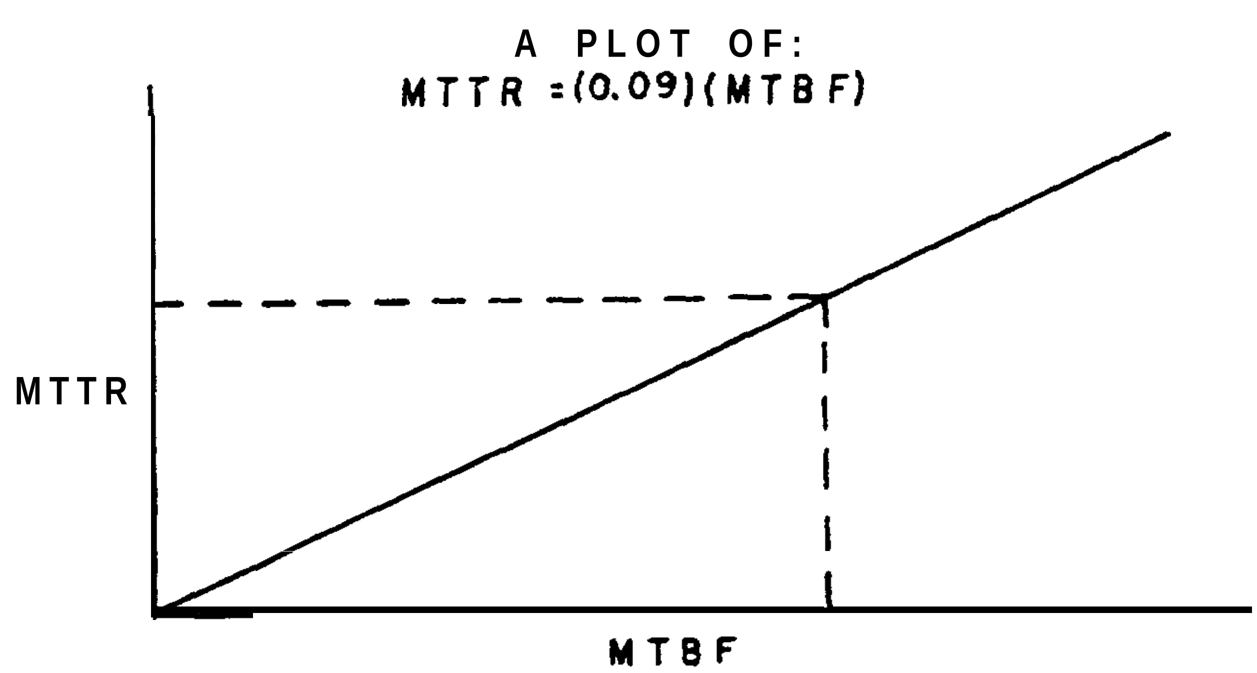
Solution

A straightforward analysis can be conducted by using the definition of Ai. Remember Ai does not consider delay times nor preventive maintenance. Should the engineers so desire and if it is considered important for this system, they could redefine MTTR to include all maintenance.

$$Ai = \frac{MTBF}{MTBF + MTTR} = 0.92$$

$$MTBF = (0.92)(MTBF + MTTR)$$
$$MTBF = (11.5)(MTTR) \text{ or}$$
$$MTTR = (0.09)(MTBF)$$

The function MTTR = (0.09)(MTBF), may be used directly, or it maybe plotted as shown below. The graph is a straight line, passing through the origin, with a slope of 0.09. For the same form of equation, the general solution is MTTR = [(1-A)/A] (MTBF), where A is inherent availability.



CASE STUDY NO. 4-2

Background

A system has an MTTR of 30 minutes and an MTBUMA of 50 hours. The intended utilization of the system is 5,000 hours per year. Ten hours of preventive maintenance are required for each 1,000 hours of operation. A mean administrative and logistic delay time of approximately 20 hours is associated with each unscheduled maintenance action.

Determine

For a one-year period, determine OT, TCM, TPM, ALDT, ST, Ao, Aa, and Ai for a utilization of 5,000 hours per year. Determine Ao if MTTR were reduced to zero. Determine the maximum number of operation hours in a year. Compare Ao and Ai.

Solution

$$TT = (365)(24) = 8,760 \text{ hours}$$

$$OT = 5,000 \text{ hours}$$

$$TCM = \frac{5,000}{50}(0.5) = 50 \text{ hours}$$

$$TPM = \frac{10}{1,000}(5,000) = 50 \text{ hours}$$

$$ALDT = \frac{5,000}{50}(20) = 2,000 \text{ hours}$$

$$ST = 8,760 - (5,000+50+50+2,000) = 8,760 - 7,100 = 1,660$$

$$Ao = \frac{5,000 + 1,660}{8,760} = 0.76$$

$$Aa = \frac{5,000}{5,000 + 50 + 50} = 0.98$$

$$Ai = \frac{5,000}{5,000 + 50} = 0.99$$

If MTTR (for corrective maintenance only) were reduced to essentially zero

$$Ao = \frac{5,000 + (1,660+50)}{5,000 + (1,660+50) + 50 + 0 + 2,000} = \frac{6,710}{8,760}$$

$$Ao = 0.77$$

NOTE: 50 hours added to numerator represents additional available standby time. This time had been spent on repair when MTTR was non-zero.

Assuming ST = O, the maximum possible operating hours in a year can be determined as follows:

$$Ao = \frac{5{,}000}{5{,}000 + 50 + 50 + 2{,}000} = 0.704$$

(Ao)(hours/year) = (0.704)(8,760) = 6,153 hours maximum.

An alternative method for determining maximum possible operating hours assuming ST = O is to solve the following equation for x.

$$8760 - \frac{0.5}{50}x + \frac{10}{1000}x + \frac{20}{50} \quad X = X,$$

where

$$\frac{0.5}{50}x = TCM$$

$$\& \quad x = TPM$$

$$\frac{20}{50}x = ALDT.$$

The solution is x = 6,169. The difference in the two values occurs as a consequence of rounding Ao (0.704) to three significant digits.

CASE STUDY NO. 4-3

Background

Test planning requires that an assessment be made of some basic program requirements . During this assessment, you observe that some of the assumptions concerning availability assessment are questionable. Consider the case where system availability is being computed, and let us assume that we have the option of using either a 5-day test period or a 7-day test period. Note that neither system utilization nor maintenance occurs on 2 of the 7 days. A close review of these conditions is warranted, particularly one which permits the utilization of a 7-day week for total time when in fact additional system usage does not occur during 2 days of this period.

Determine

What is the impact of the utilization period choice on Ao?.

For purposes of this review, we will utilize the following parameters:

OT = 10 hours
TPM = 5 hours
TCM = 60 hours
ALDT = 22 hours

$$A_o = \frac{OT + ST}{OT + ST + TPM + TCM + ALDT}$$

Solution

For: 7 Days

OT = 10 hours
ST = 158 hours

$$A_o = \frac{168}{168 + 87}$$

Ao = **0.66**

5 Days

OT = 10 hours
ST = 110 hours

$$A_o = \frac{120}{120 + 87}$$

Ao = 0.58

Commentary

Note the higher value obtained by including the two additional non-usage days.

CASE STUDY NO. 4-4

Background

Because operational availability is a composite of system, support, and environmental factors, it is a useful tool in conducting analyses of the various parameters. The following is an example of this analysis.

Determine

Develop an expression which defines MTBF as a function of OT, TT, availability, and logistics down time.

Solution

We start with the expression for operational availability:

$$A_o = \frac{OT + ST}{OT + ST + TPM + TCM + ALDT} . \tag{1}$$

Since TPM + TCM + ALDT = TDT, total down time,

$$A_o = \frac{OT + ST}{OT + ST + TDT} . \tag{2}$$

The denominator of this equation is total time,

$$OT + ST + TDT = TT,$$

and the numerator equals total time less TDT, thus

$$A_o = \frac{TT - TDT}{TT}$$

$$A_o = 1 - \frac{TDT}{TT} . \tag{3}$$

Define DTF as the down time per failure. It is necessary to base the Ao value on MTBF so that the MTBF may be isolated and computed.

The number of failures, r, is equal to OT/MTBF. Total down time is then'

$$TDT = (DTF)(OT/MTBF) + TPM + (ALDT)_p . \text{ Assume } (ADLT)_p \cong 0.$$

Substituting this expression in the last equation of step 3, we obtain

$$A_o = 1 - \frac{(DTF)(OT)}{(TT)(MTBF)} - \frac{TPM}{TT} , \tag{4}$$

Solving for the MTBF, we obtain

$$MTBF = \frac{(DTF)(OT)}{(1-Ao)(TT) - TPM} \tag{5}$$

Using the following values

TT = 90 days x 24 hrs/day = 2,160 hours

OT = 23 missions x 40 hours per mission = 920 hours

DTF = 24 hours per failure

TPM = 100 hours

and substituting into (5), we obtain

$$MTBF = \frac{(24)(920)}{(1-0.8)(2,160) - 100} = 50.0 \text{ hours.}$$

NOTE: When using this definition of MTBF, it is important to verify that the standby time is not forced below a zero value by erroneously defining OT, TDT, and TT.

CASE STUDY NO. 4-5

Background

A system currently in late development has exhibited an operational availability of 0.66. The user has stipulated that an operational availability of a 0.75 minimum is required. In order to improve system operational availability, it is decided to change the maintenance concept on several low-reliability units. The current circuit card remove/replace concept will be changed to a black box remove/replace. The following tabulations list the characteristics of the existing equipment and those desired after the system maintenance concept has been revised in an attempt to improve operational availability.

Existing Elements	Desired Elements
TT = 168 hours	TT = 168 hours
TPM = 5 hours	TPM = 5 hours
TCM = 60 hours	TCM = to be determined
ALDT = 22 hours	ALDT = 22 hours
Ao = 0.66	Ao = 0.75

Determine

New required value of TCM which must be realized if the desired Ao increase is to be achieved.

Solution

$$Ao = \frac{OT + ST}{OT + ST + TCM + TPM + ALDT} = \frac{TT}{TT + TCM + TPM + ALDT}$$

$$Ao = \frac{168}{168 + 5 + TCM + 22} = \frac{168}{TCM + 195}$$

Since Ao = 0.75,

TCM = 27.4 hours

Commentary

Of course, the reasonableness or attainability of such a reduction must be considered. Increased operational availability also can be obtained by decreasing TPM or ALDT.